



Ministry/Organization Name/Student Innovation: Department of Space, Indian Space Research Organisation

PS Code: SS612

Problem Statement Title: Prediction of TEC Variations with Artificial Intelligence using Space Weather Data

Team Name: AZTECH ALURE

Team Leader Name: RASHI JAIN

Institute Code (AISHE): C- 25248

Problem Category: Software

Theme Name: Disaster Management





Team Leader : Rashi Jain

Team Member : Hitesh Kumar

Team Member : Priyansh Bhardwaj

Team Member : Manav Gandhi

Team Member : Aikaj Pathania

Team Member : Dishant Gupta



The ionospheric electron density is sensitive to the space weather parameters like Sunspot numbers, F10.7, Interplanetary magnetic field etc. and shows variation with respect to them. These parameters are detected and measured at L1 point (currently by ESA / NASA satellites) and are transmitted to earth. The above mentioned parameters affect the ionospheric TEC, which in turn shows abrupt variations and deviations from the nominal characteristics. Therefore, these unconventionalities, which are typically observed during solar and geomagnetic storms, are necessary to be identified. This is also important, because the performance of the GNSS system, which is currently driving millions of applications, are also affected by the ionospheric variabilities. So, prediction of the TEC provides a handle to take necessary actions to avoid or mitigate the resultant impairments arising out of the above facts. For the purpose, the time sequence of space-weather parameters, along with the local time, location, season, date etc. can be related to the same for the vertical TEC and a definitive relationship can be established using Artificial Intelligence (AI) methods, like neural networks or other deep learning algorithms. The problem requires the development of the proper AI algorithm to use the available space weather and other data to predict the TEC variations at one particular location on the earth, preferably over the geomagnetic equator.



Making a web application that helps to :

1. To visualize global and regional TEC variations and investigate the anomalies.
2. To predict the TEC by Machine Learning models trained with time sequence weather data recorded by GNSS receiver over years.
3. To measure and improve accuracy of prediction so that disruptive effect of unconventional variations on satellite communication can be mitigated
4. To observe the impact of solar and geomagnetic storms on TEC variations and also find its correlation with weather data.
5. To compare various ML models and find out pros and cons.



The Total Electron Content (TEC) is the total number of electrons present along a path between a radio transmitter and receiver. Radio waves are affected by the presence of electrons. The more electrons in the path of the radio wave, the more the radio signal will be affected. For ground to satellite communication and satellite navigation, TEC is a good parameter to monitor for possible space weather impacts.

TEC is measured in electrons per square meter. By convention, 1 TEC Unit TECU = 10^{16} electrons/m². Vertical TEC values in Earth's ionosphere can range from a few to several hundred TECU.

The TEC in the ionosphere is modified by changing solar Extreme Ultra-Violet radiation, geomagnetic storms, and the atmospheric waves that propagate up from the lower atmosphere. The TEC will therefore depend on local time, latitude, longitude, season, geomagnetic conditions, solar cycle and activity, and troposphere conditions. The propagation of radio waves is affected by the ionosphere. The velocity of radio waves changes when the signal passes through the electrons in the ionosphere. The total delay suffered by a radio wave propagating through the ionosphere depends both on the frequency of the radio wave and the TEC between the transmitter and the receiver. At some frequencies the radio waves pass through the ionosphere. At other frequencies, the waves are reflected by the ionosphere.



1. Ionex Format

The VTEC is read from a IONEX file. A stream contains, for a given day, the values of the TEC for each hour of the day. Values are given on a global $2.5^\circ \times 5.0^\circ$ (latitude x longitude) grid.

A bilinear interpolation is performed the case of the user initialize the latitude and the longitude with values that are not contained in the stream.

A temporal interpolation is also performed to compute the VTEC at the desired date.

IONEX files are obtained from [The Crustal Dynamics Data Information System](#).

The files have to be extracted to UTF-8 text files before being read by this loader.



Ionex Format



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1.0          IONOSPHERE MAPS      MIX      IONEX VERSION / TYPE
cmpcmb v1.2   GRL/UWM             16-jan-20 13:02  PGM / RUN BY / DATE
ionex file containing IGS COMBINED Ionosphere maps  COMMENT
global ionosphere maps for day 001, 2020           DESCRIPTION
IONEX file containing the COMBINED IGS TEC MAPS and DCBs DESCRIPTION
IONEX files of the following IAACs were combined: cod DESCRIPTION
                                                    esa DESCRIPTION
                                                    jpl DESCRIPTION
                                                    upc DESCRIPTION
Contact address: Andrzej Krankowski                DESCRIPTION
Geodynamics Research Laboratory                    DESCRIPTION
University of Warmia and Mazury (GRL/UWM)          DESCRIPTION
Oczapowski St. 1                                  DESCRIPTION
10-957-Olsztyn, POLAND                            DESCRIPTION
e-mail: kand@uwm.edu.pl                           DESCRIPTION
                                                    DESCRIPTION
2020         1         1         0         0         0  EPOCH OF FIRST MAP
2020         1         2         0         0         0  EPOCH OF LAST MAP
7200                                     INTERVAL
13                                           # OF MAPS IN FILE
COSZ                                           MAPPING FUNCTION
0.0                                           ELEVATION CUTOFF
combined TEC calculated as weighted mean of input TEC values OBSERVABLES USED
392                                           # OF STATIONS
32                                           # OF SATELLITES
6371.0      BASE RADIUS
2           MAP DIMENSION
450.0 450.0 0.0      HGT1 / HGT2 / DHGT
87.5 -87.5 -2.5      LAT1 / LAT2 / DLAT
-180.0 180.0 5.0      LON1 / LON2 / DLON
-1                                           EXPONENT
TEC values in 0.1 tec units; 9999, if no value available COMMENT
DCB values in nanoseconds, reference is Sum_of_SatDCBs = 0 COMMENT

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100 101 102 103 104 105 106 107 108 109 110 111 112 113 114 115 116 117 118 119 120 121 122 123 124 125 126 127 128 129 130 131 132 133 134 135 136 137 138 139 140 141 142 143 144 145 146 147 148 149 150 151 152 153 154 155 156 157 158 159 160 161 162 163 164 165 166 167 168 169 170 171 172 173 174 175 176 177 178 179 180 181 182 183 184 185 186 187 188 189 190 191 192 193 194 195 196 197 198 199 200 201 202 203 204 205 206 207 208 209 210 211 212 213 214 215 216 217 218 219 220 221 222 223 224 225 226 227 228 229 230 231 232 233 234 235 236 237 238 239 240 241 242 243 244 245 246 247 248 249 250 251 252 253 254 255 256 257 258 259 260 261 262 263 264 265 266 267 268 269 270 271 272 273 274 275 276 277 278 279 280 281 282 283 284 285 286 287 288 289 290 291 292 293 294 295 296 297 298 299 300 301 302 303 304 305 306 307 308 309 310 311 312 313 314 315 316 317 318 319 320 321 322 323 324 325 326 327 328 329 330 331 332 333 334 335 336 337 338 339 340 341 342 343 344 345 346 347 348 349 350 351 352 353 354 355 356 357 358 359 360 361 362 363 364 365 366 367 368 369 370 371 372 373 374 375 376 377 378 379 380 381 382 383 384 385 386 387 388 389 390 391 392 393 394 395 396 397 398 399 400 401 402 403 404 405 406 407 408 409 410 411 412 413 414 415 416 417 418 419 420 421 422 423 424 425 426 427 428 429 430 431 432 433 434 435 436 437 438 439 440 441 442 443 444 445 446 447 448 449 450 451 452 453 454 455 456 457 458 459 460 461 462 463 464 465 466 467 468 469 470 471 472 473 474 475 476 477 478 479 480 481 482 483 484 485 486 487 488 489 490 491 492 493 494 495 496 497 498 499 500 501 502 503 504 505 506 507 508 509 510 511 512 513 514 515 516 517 518 519 520 521 522 523 524 525 526 527 528 529 530 531 532 533 534 535 536 537 538 539 540 541 542 543 544 545 546 547 548 549 550 551 552 553 554 555 556 557 558 559 560 561 562 563 564 565 566 567 568 569 570 571 572 573 574 575 576 577 578 579 580 581 582 583 584 585 586 587 588 589 590 591 592 593 594 595 596 597 598 599 600 601 602 603 604 605 606 607 608 609 610 611 612 613 614 615 616 617 618 619 620 621 622 623 624 625 626 627 628 629 630 631 632 633 634 635 636 637 638 639 640 641 642 643 644 645 646 647 648 649 650 651 652 653 654 655 656 657 658 659 660 661 662 663 664 665 666 667 668 669 670 671 672 673 674 675 676 677 678 679 680 681 682 683 684 685 686 687 688 689 690 691 692 693 694 695 696 697 698 699 700 701 702 703 704 705 706 707 708 709 710 711 712 713 714 715 716 717 718 719 720 721 722 723 724 725 726 727 728 729 730 731 732 733 734 735 736 737 738 739 740 741 742 743 744 745 746 747 748 749 750 751 752 753 754 755 756 757 758 759 760 761 762 763 764 765 766 767 768 769 770 771 772 773 774 775 776 777 778 779 780 781 782 783 784 785 786 787 788 789 790 791 792 793 794 795 796 797 798 799 800 801 802 803 804 805 806 807 808 809 810 811 812 813 814 815 816 817 818 819 820 821 822 823 824 825 826 827 828 829 830 831 832 833 834 835 836 837 838 839 840 841 842 843 844 845 846 847 848 849 850 851 852 853 854 855 856 857 858 859 860 861 862 863 864 865 866 867 868 869 870 871 872 873 874 875 876 877 878 879 880 881 882 883 884 885 886 887 888 889 890 891 892 893 894 895 896 897 898 899 900 901 902 903 904 905 906 907 908 909 910 911 912 913 914 915 916 917 918 919 920 921 922 923 924 925 926 927 928 929 930 931 932 933 934 935 936 937 938 939 940 941 942 943 944 945 946 947 948 949 950 951 952 953 954 955 956 957 958 959 960 961 962 963 964 965 966 967 968 969 970 971 972 973 974 975 976 977 978 979 980 981 982 983 984 985 986 987 988 989 990 991 992 993 994 995 996 997 998 999 1000 1001 1002 1003 1004 1005 1006 1007 1008 1009 1010 1011 1012 1013 1014 1015 1016 1017 1018 1019 1020 1021 1022 1023 1024 1025 1026 1027 1028 1029 1030 1031 1032 1033 1034 1035 1036 1037 1038 1039 1040 1041 1042 1043 1044 1045 1046 1047 1048 1049 1050 1051 1052 1053 1054 1055 1056 1057 1058 1059 1060 1061 1062 1063 1064 1065 1066 1067 1068 1069 1070 1071 1072 1073 1074 1075 1076 1077 1078 1079 1080 1081 1082 1083 1084 1085 1086 1087 1088 1089 1090 1091 1092 1093 1094 1095 1096 1097 1098 1099 1100 1101 1102 1103 1104 1105 1106 1107 1108 1109 1110 1111 1112 1113 1114 1115 1116 1117 1118 1119 1120 1121 1122 1123 1124 1125 1126 1127 1128 1129 1130 1131 1132 1133 1134 1135 1136 1137 1138 1139 1140 1141 1142 1143 1144 1145 1146 1147 1148 1149 1150 1151 1152 1153 1154 1155 1156 1157 1158 1159 1160 1161 1162 1163 1164 1165 1166 1167 1168 1169 1170 1171 1172 1173 1174 1175 1176 1177 1178 1179 1180 1181 1182 1183 1184 1185 1186 1187 1188 1189 1190 1191 1192 1193 1194 1195 1196 1197 1198 1199 1200 1201 1202 1203 1204 1205 1206 1207 1208 1209 1210 1211 1212 1213 1214 1215 1216 1217 1218 1219 1220 1221 1222 1223 1224 1225 1226 1227 1228 1229 1230 1231 1232 1233 1234 1235 1236 1237 1238 1239 1240 1241 1242 1243 1244 1245 1246 1247 1248 1249 1250 1251 1252 1253 1254 1255 1256 1257 1258 1259 1260 1261 1262 1263 1264 1265 1266 1267 1268 1269 1270 1271 1272 1273 1274 1275 1276 1277 1278 1279 1280 1281 1282 1283 1284 1285 1286 1287 1288 1289 1290 1291 1292 1293 1294 1295 1296 1297 1298 1299 1300 1301 1302 1303 1304 1305 1306 1307 1308 1309 1310 1311 1312 1313 1314 1315 1316 1317 1318 1319 1320 1321 1322 1323 1324 1325 1326 1327 1328 1329 1330 1331 1332 1333 1334 1335 1336 1337 1338 1339 1340 1341 1342 1343 1344 1345 1346 1347 1348 1349 1350 1351 1352 1353 1354 1355 1356 1357 1358 1359 1360 1361 1362 1363 1364 1365 1366 1367 1368 1369 1370 1371 1372 1373 1374 1375 1376 1377 1378 1379 1380 1381 1382 1383 1384 1385 1386 1387 1388 1389 1390 1391 1392 1393 1394 1395 1396 1397 1398 1399 1400 1401 1402 1403 1404 1405 1406 1407 1408 1409 1410 1411 1412 1413 1414 1415 1416 1417 1418 1419 1420 1421 1422 1423 1424 1425 1426 1427 1428 1429 1430 1431 1432 1433 1434 1435 1436 1437 1438 1439 1440 1441 1442 1443 1444 1445 1446 1447 1448 1449 1450 1451 1452 1453 1454 1455 1456 1457 1458 1459 1460 1461 1462 1463 1464 1465 1466 1467 1468 1469 1470 1471 1472 1473 1474 1475 1476 1477 1478 1479 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1880 1881 1882 1883 1884 1885 1886 1887 1888 1889 1890 1891 1892 1893 1894 1895 1896 1897 1898 1899 1900 1901 1902 1903 1904 1905 1906 1907 1908 1909 1910 1911 1912 1913 1914 1915 1916 1917 1918 1919 1920 1921 1922 1923 1924 1925 1926 1927 1928 1929 1930 1931 1932 1933 1934 1935 1936 1937 1938 1939 1940 1941 1942 1943 1944 1945 1946 1947 1948 1949 1950 1951 1952 1953 1954 1955 1956 1957 1958 1959 1960 1961 1962 1963 1964 1965 1966 1967 1968 1969 1970 1971 1972 1973 1974 1975 1976 1977 1978 1979 1980 1981 1982 1983 1984 1985 1986 1987 1988 1989 1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017 2018 2019 2020 2021 2022 2023 2024 2025 2026 2027 2028 2029 2030 2031 2032 2033 2034 2035 2036 2037 2038 2039 2040 2041 2042 2043 2044 2045 2046 2047 2048 2049 2050 2051 2052 2053 2054 2055 2056 2057 2058 2059 2060 2061 2062 2063 2064 2065 2066 2067 2068 2069 2070 2071 2072 2073 2074 2075 2076 2077 2078 2079 2080 2081 2082 2083 2084 2085 2086 2087 2088 2089 2090 2091 2092 2093 2094 2095 2096 2097 2098 2099 2100 2101 2102 2103 2104 2105 2106 2107 2108 2109 2110 2111 2112 2113 2114 2115 2116 2117 2118 2119 2120 2121 2122 2123 2124 2125 2126 2127 2128 2129 2130 2131 2132 2133 2134 2135 2136 2137 2138 2139 2140 2141 2142 2143 2144 2145 2146 2147 2148 2149 2150 2151 2152 2153 2154 2155 2156 2157 2158 2159 2160 2161 2162 2163 2164 2165 2166 2167 2168 2169 2170 2171 2172 2173 2174 2175 2176 2177 2178 2179 2180 2181 2182 2183 2184 2185 2186 2187 2188 2189 2190 2191 2192 2193 2194 2195 2196 2197 2198 2199 2200 2201 2202 2203 2204 2205 2206 2207 2208 2209 2210 2211 2212 2213 2214 2215 2216 2217 2218 2219 2220 2221 2222 2223 2224 2225 2226 2227 2228 2229 2230 2231 2232 2233 2234 2235 2236 2237 2238 2239 2240 2241 2242 2243 2244 2245 2246 2247 2248 2249 2250 2251 2252 2253 2254 2255 2256 2257 2258 2259 2260 2261 2262 2263 2264 2265 2266 2267 2268 2269 2270 2271 2272 2273 2274 2275 2276 2277 2278 2279 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2480 2481 2482 2483 2484 2485 2486 2487 2488 2489 2490 2491 2492 2493 2494 2495 2496 2497 2498 2499 2500 2501 2502 2503 2504 2505 2506 2507 2508 2509 2510 2511 2512 2513 2514 2515 2516 2517 2518 2519 2520 2521 2522 2523 2524 2525 2526 2527 2528 2529 2530 2531 2532 2533 2534 2535 2536 2537 2538 2539 2540 2541 2542 2543 2544 2545 2546 2547 2548 2549 2550 2551 2552 2553 2554 2555 2556 2557 2558 2559 2560 2561 2562 2563 2564 2565 2566 2567 2568 2569 2570 2571 2572 2573 2574 2575 2576 2577 2578 2579 2580 2581 2582 2583 2584 2585 2586 2587 2588 2589 2590 2591 2592 2593 2594 2595 2596 2597 2598 2599 2600 2601 2602 2603 2604 2605 2606 2607 2608 2609 2610 2611 2612 2613 2614 2615 2616 2617 2618 2619 2620 2621 2622 2623 2624 262
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2. Rinex Format

Receiver Independent Exchange Format (RINEX) is a data interchange format for raw satellite navigation system data. This allows the user to post-process the received data to produce a more accurate result — usually with other data unknown to the original receiver, such as better models of the atmospheric conditions at time of measurement.

The final output of a navigation receiver is usually its position, speed or other related physical quantities. However, the calculation of these quantities are based on a series of measurements from one or more satellite constellations. Although receivers calculate positions in real time, in many cases it is interesting to store intermediate measures for later use. RINEX is the standard format that allows the management and disposal of the measures generated by a receiver, as well as their off-line processing by a multitude of applications, whatever the manufacturer of both the receiver and the computer application.

The RINEX format is designed to evolve over time, adapting to new types of measurements and new satellite navigation systems.



Rinex Format



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3.02 OBSERVATION DATA M: MIXED RINEX VERSION / TYPE
Leica Infinity 2.1 20170330 192656 UTC PGM / RUN BY / DATE
2 MARKER NAME
2 MARKER NUMBER
GEODETTIC MARKER TYPE
3248294 LEICA GS16 6.13 OBSERVER / AGENCY
LEIGS16 NONE REC # / TYPE / VERS
808630.6740 -4918582.2152 3966416.8757 ANT # / TYPE
1.7998 0.0000 0.0000 APPROX POSITION XYZ
G 16 C1C L1C D1C S1C C2S L2S D2S S2S C2W L2W D2W S2W C5Q ANTENNA: DELTA H/E/N
L5Q D5Q S5Q SYS / # / OBS TYPES
R 8 C1C L1C D1C S1C C2P L2P D2P S2P SYS / # / OBS TYPES
DBHZ SIGNAL STRENGTH UNIT
5.000 INTERVAL
2017 02 24 18 46 50.0000000 GPS TIME OF FIRST OBS
2017 02 24 19 20 5.0000000 GPS TIME OF LAST OBS
0 RCV CLOCK OFFS APPL
G L2S -0.25000 SYS / PHASE SHIFT
G L2X -0.25000 SYS / PHASE SHIFT
R L2P 0.25000 SYS / PHASE SHIFT
E L8Q -0.25000 SYS / PHASE SHIFT
C1C -71.940 C1P -71.940 C2C -71.940 C2P -71.940 GLONASS COD/PHS/BIS
17 LEAP SECONDS
END OF HEADER

> 2017 02 24 18 46 50.0000000 0 15
G03 21918730.000 115183701.61917 952.709 46.850 21918734.200 89753546.96317 742.370 44.700 21918734.300 89753549.95916
G14 21149467.700 111141203.35418 -1353.300 49.200 21149469.340 86603539.47316
G16 22084769.920 116056252.94717 3429.903 47.100 22084772.220 90433448.46816
G22 21509499.440 113033183.37818 -283.437 49.150 21509499.320 88077803.93916
G23 24281434.560 127599798.28217 3152.119 43.600 24281436.380 99428417.08215
G25 24183125.240 127083178.30717 -3490.522 43.350 24183130.160 99025866.50017 -2719.890 42.050 24183130.400 99025868.49016
G26 20762467.020 109107500.80518 1575.543 50.300 20762471.560 85018844.70118 1227.697 47.550 20762471.900 85018847.69817
G29 23908430.020 125639642.15416 988.559 37.050 23908435.400 97901048.87215 770.309 32.300 23908434.920 97901042.89814
G31 20879667.800 109723393.74418 -1523.864 51.100 20879668.480 85498750.44217 -1187.427 45.550 20879668.180 85498750.43416
G32 22828108.760 119962521.61117 -2669.465 46.550 22828114.320 93477303.09017 -2080.104 43.150 22828114.340 93477303.08616
R02 19139367.300 102131329.48318 -592.353 51.150 19139371.560 79435492.48317 -460.719 46.350
R03 21201191.800 113491637.28118 3294.613 47.800 21201194.240 88271280.28817 2562.476 44.900
R11 22856297.160 122137118.42817 -3572.543 44.800 22856302.060 94995557.49017 -2778.647 42.900
R12 19617304.020 104792114.13418 -1509.670 49.700
R13 20848624.420 111330490.93017 2207.254 44.150 20848629.600 86590397.95217 1716.754 42.000
> 2017 02 24 18 46 55.0000000 0 15
G03 21917824.400 115178942.66907 949.587 47.000 21917828.620 89749838.68007 739.937 44.850 21917828.700 89749841.67606
G14 21150755.880 111147972.70408 -1355.327 49.150 21150757.520 86608814.29106
G16 22081506.980 116039106.20807 3427.926 46.950 22081509.260 90420087.40906
G22 21509770.220 113034606.29908 -286.646 49.100 21509770.080 88078912.70706
G23 24278435.100 127584036.10007 3151.794 44.350 24278436.920 99416134.88005
G25 24186446.520 127100631.83807 -3491.784 42.900 24186451.480 99039466.65807 -2720.871 41.600 24186451.700 99039468.64005
G26 20760968.900 109099628.19208 1572.565 50.200 20760973.440 85012710.20508 1225.378 47.500 20760973.780 85012713.20507
G29 23907490.140 125634703.13806 985.689 37.650 23907495.460 97897200.32505 768.073 32.700 23907495.000 97897194.32804
G31 20881117.880 109731013.95008 -1525.104 51.050 20881118.540 85504688.26707 -1188.394 45.550 20881118.260 85504688.26107
G32 22830649.020 119975870.72507 -2671.000 46.650 22830654.560 93487704.99107 -2081.300 43.000 22830654.580 93487704.99506
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Several global TEC prediction models have been constructed and evaluated, such as -

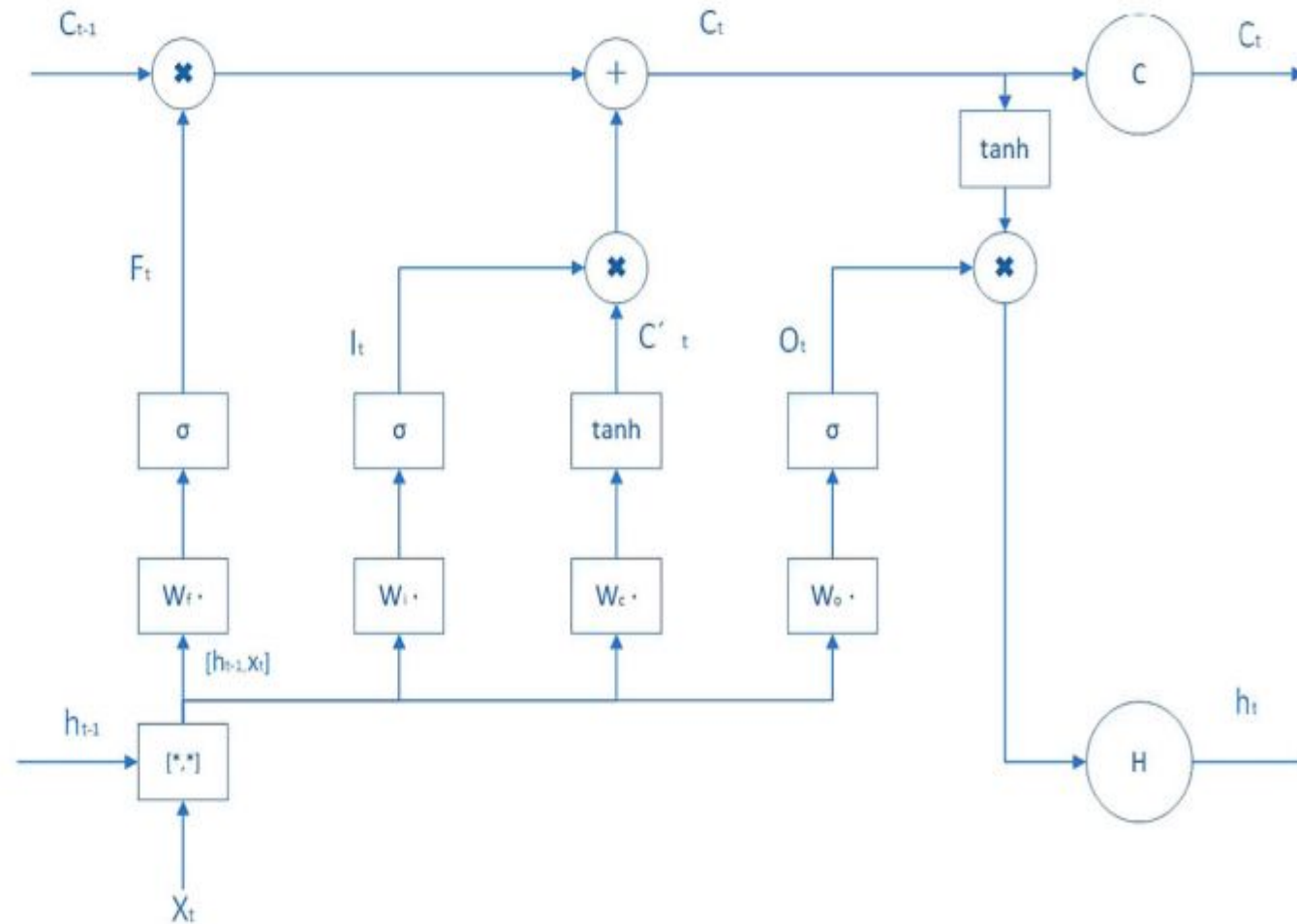
1. Klobuchar model for estimating Global Positioning System (GPS) signal delay (Klobuchar 1987)
2. International Reference Ionosphere (IRI) model for estimating specified ionospheric parameters
3. NeQuick model for estimating electron density
4. NeQuick-G model adopted by the Galileo system for its single-frequency users

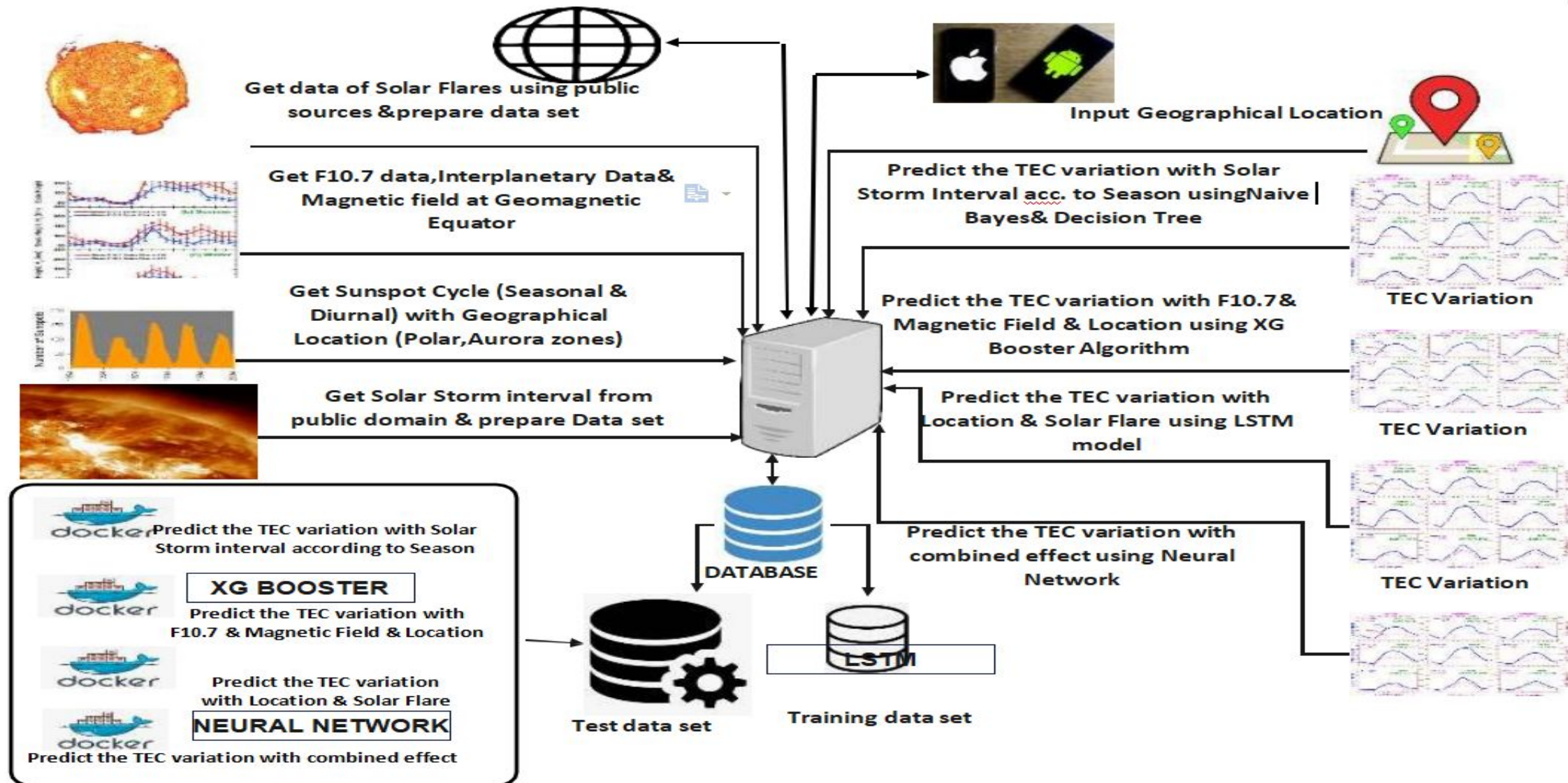
But due to different drawbacks of other models we use Long Short Term Memory (LSTM) model

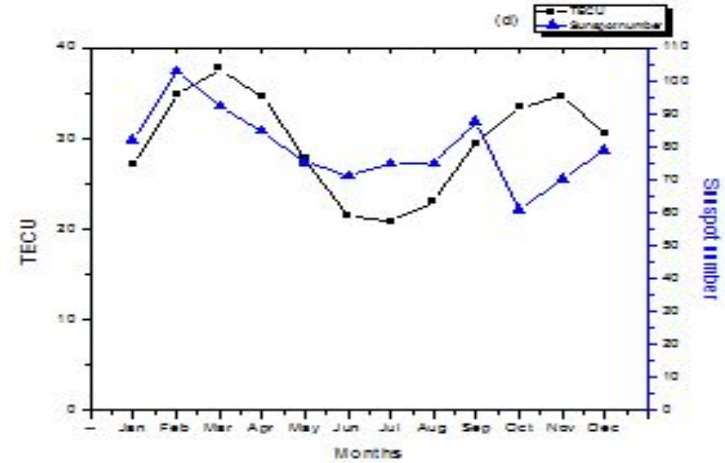
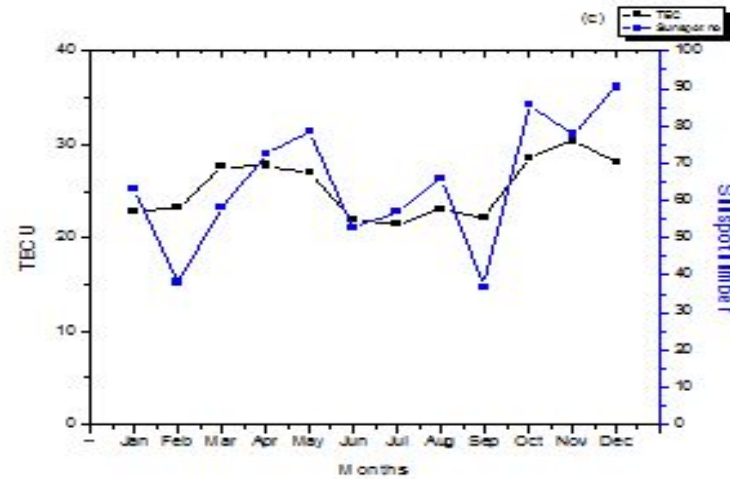
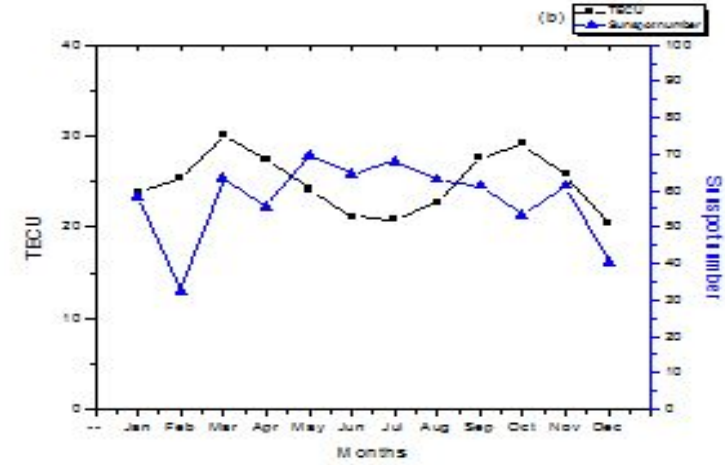
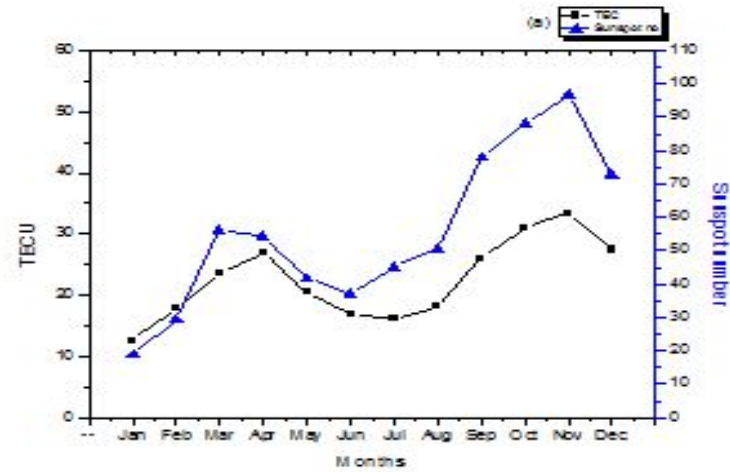


Long Short Term Memory (LSTM) is a type of Recurrent Neural Network (RNN), and it is mainly used to model time series and its long-term dependence. On the basis of simple recurrent networks, LSTM adds memory cells to each neuron unit of the hidden layer to store information for a long period of time, so that the memory information in the time series is controllable. Using three gates (i.e., forget, input, and output gates), LSTM can select the amount of information of the previous cell to be included, so that it is capable of learning both long- and short-term dependencies between features, which is beneficial to the prediction of time series. The hidden layer of LSTM has three types of gate: forget gate (f_t), input gate (i_t), and output gate (o_t); C and H represent cell state and output, respectively, and subscripts $t-1$ and t represent previous and current time, respectively. The forget gate determines to what extent to forget the previous information. The input gate determines how much of the input at the current time the cell state retains to avoid the input of useless information. The output gate decides what the current output value should be.

Structure of LSTM model









1. <https://www.swpc.noaa.gov/phenomena/f107-cm-radio-emissions>
2. <https://github.com/gnss-lab>
3. <https://cddis.nasa.gov/archive/gnss/products/ionosphere/>
4. https://www.researchgate.net/publication/267841641_Variation_of_Total_Electron_Content_TEC_and_Their_Effect_on_GNSS_over_Akure_Nigeria
5. https://www.researchgate.net/publication/259123752_Sunspot_numbers_interplanetary_magnetic_field_and_cosmic_ray_intensity_at_earth_Nexus_for_the_twentieth_century
6. <https://www.scirp.org/journal/paperinformation.aspx?paperid=76760>
7. <https://doi.org/10.31401/SunGeo.2019.02.05>
8. <https://sidc.be/silso/datafiles>
9. <https://cddis.nasa.gov/archive/gnss/products/ionosphere/2022/>

Thank you!